MULTIMEDIA UNIVERSITY

STUDENT ID NO

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# MULTIMEDIA UNIVERSITY

# FINAL EXAMINATION

**TRIMESTER 2 2022/2023 (TERM ID 2220)**

## EEL1206 – INTRODUCTION TO MACHINES AND POWER SYSTEMS

( EE, CE, TE, NT )

7 JULY 2023
9.00 a.m - 11.00 a.m
( 2 Hours )

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**INSTRUCTIONS TO STUDENTS**

1. This question paper consists of **11** pages including the cover page and Appendix. There are **FOUR** questions in this paper.

2. Attempt **ALL** questions. All questions carry equal marks and the distribution of marks for each question is given.

3. Some useful formulae are given in the Appendix section.

4. Please write all your answers in the Answer Booklet provided.

## Question 1

(a) Identify **TWO** statements that are **FALSE**:

A. Generator is an electric machine that converts mechanical power to electrical power through the action of magnetic field and rotation.

B. Transformer is a static device with two or more windings, which converts electrical power from one voltage level to another voltage level at different frequencies.

C. A motor is supplying 60 N-m of torque to its load, where the shaft of the motor is turning at 1800 revolution/min. The corresponding mechanical power supplied to the load is 18.16 hp.

D. Figure Q1(a) depicts a wire carrying a current in the presence of a magnetic field, with a magnetic flux density of 0.5 T, directed into the page. The wire has a length of 1.25 m, and carries a current of 0.8 A in the direction from the bottom to the top of the page. The induced force is 0.5 N, directed to the left.

[2 marks]

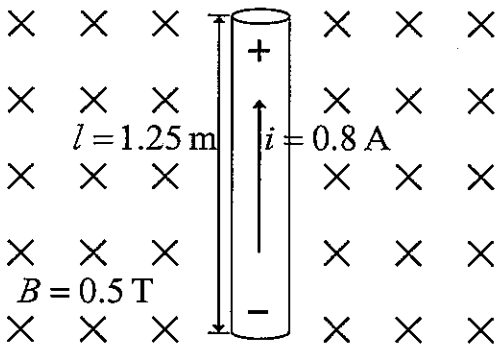



Figure Q1(a)

(b) Figure Q1(b) illustrates a ferromagnetic core structure with a relative permeability of 2500, where a current-carrying coil of wire with 850 turns is wrapped around the left leg of the core. The depth of the core is 9 cm, and the other dimensions of the core are indicated in the diagram. Due to the fringing effect, the effective area of the air gap is 14% larger than the physical core area. Given that a flux of 8 mWb is established in the air gap.
(Permeability of free space, $\mu_0 = 4\pi \times 10^{-7}$H/m)

(i) Determine the total reluctance of the core structure. [5 marks]

(ii) Calculate the magnetic field intensity of the air gap. [3 marks]

(iii) Find the current $i$ that is required to establish the flux. [3 marks]

**Continued...**

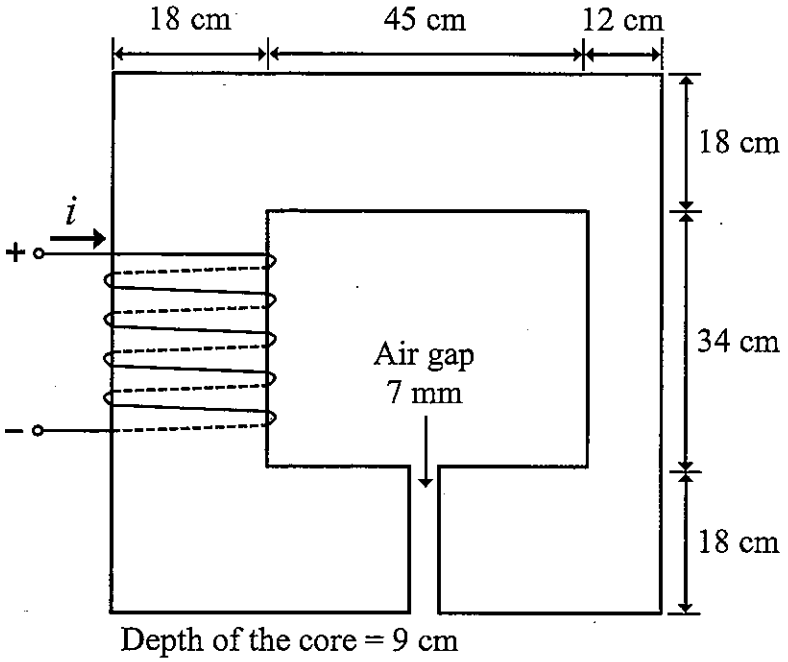



Figure Q1(b)

(c) Consider a balanced three-phase power system comprising of the following:

- Ideal Y-connected generator with a phase voltage $\mathbf{V}_{an} = 640\angle 18°$ V, where a positive phase sequence is assumed;
- Power transmission line with an impedance $\mathbf{Z}_{line} = (1.8 + j2.2)\ \Omega$ per phase; and
- Y-connected load with an impedance $\mathbf{Z}_Y = (24 + j36)\ \Omega$ per phase.

(i) Sketch the per-phase equivalent circuit of the system. [2 marks]

(ii) Determine the line currents $\mathbf{I}_a$, $\mathbf{I}_b$, and $\mathbf{I}_c$. [4 marks]

(iii) Calculate the total real, reactive, and apparent powers consumed by the Y-connected load. [4 marks]

(iv) Find the power factor of the generator. [2 marks]

**Continued...**

## Question 2

(a) Unlike the ideal transformer, real transformers experience losses during operation. Briefly describe the following losses associated with real transformers and how they are represented in a transformer equivalent circuit:

(i) Copper losses

(ii) Eddy current and hysteresis losses

(iii) Leakage fluxes

(iv) Finite permeability of the core

[8 marks]

(b) Figure Q2(a) shows an approximate equivalent circuit diagram of a transformer, referred to the secondary side.

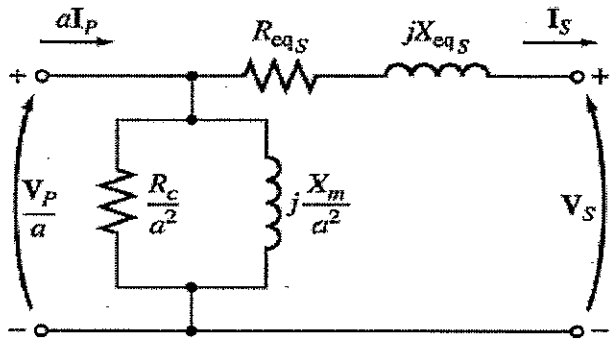



Figure Q2(a)

(i) Determine the copper and core losses of the transformer if $V_p = 240kV$, $I_s = 350A$, $R_C = 640k\Omega$, $R_{eqS} = 0.4\Omega$ and $a = 16$.

[5 marks]

(ii) Evaluate the performance of the transformer in terms of voltage regulation and efficiency if $V_S = 13.8kV$ and $P_{out} = 4200kW$.

[4 marks]

(c) When the primary and secondary winding are electrically connected, or when they are even the same winding for part of their length, the transformer is an autotransformer. Explain the advantages and disadvantages of an autotransformer.

[3 marks]

**Continued...**

(d) Figure Q2(b) shows an equivalent circuit diagram of a step-down autotransformer.

(i) Find the turn ratio of the transformer if $N_C = 600$ and $N_{se} = 400$.

[1 mark]

(ii) Compute primary voltage $V_1$ if the secondary voltage $V_2 = 480V$

[1 mark]

(iii) Determine $I_1$, $I_2$ and $I_C$ if the power rating of the transformer is $96kVA$.

[3 marks]

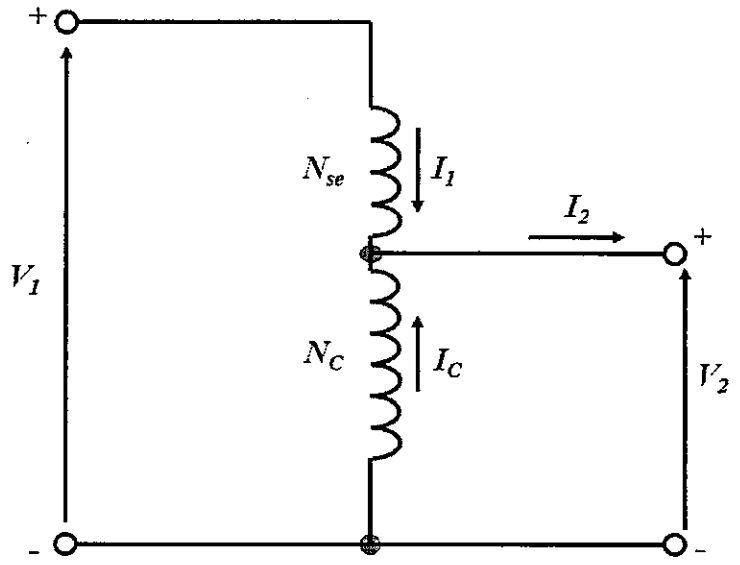



Figure Q2(b)

**Continued...**

## Question 3

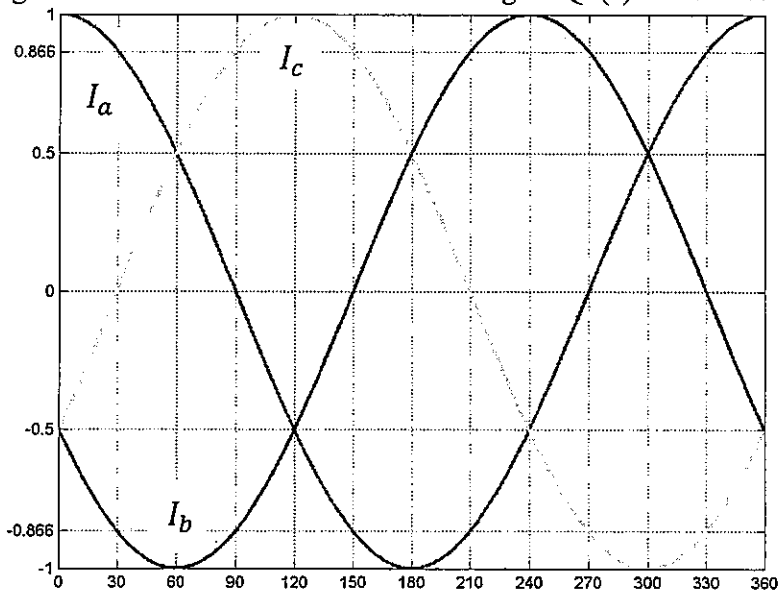
(a) (i) Describe the terms slip and slip speed in an induction motor.

[3 marks]

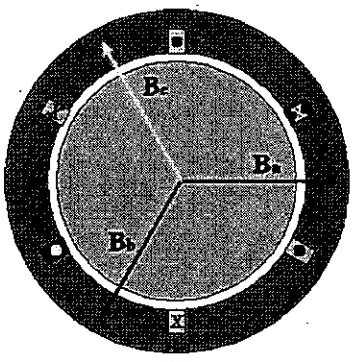
(ii) In your own words, explain why an induction motor cannot operate at synchronous speed.

[3 marks]

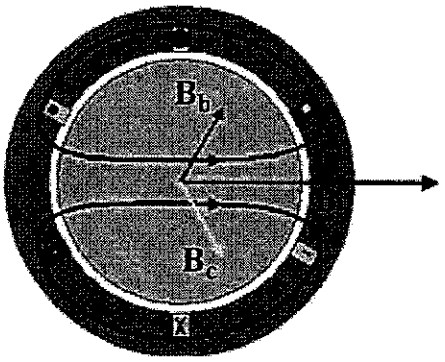
(b) Figure Q3(a) shows the plot of the currents passing through a 3-phase squirrel cage induction motor, while Figure Q3(b) shows the respective magnetic field directions associated with the three phase currents. Using Figure Q3(b) as reference, examine the direction of the rotating magnetic field produced at 90° and 180°. An example of the magnetic field direction at 0° is shown in Figure Q3(c) as reference.




(a)




(b)




(c)

Figure Q3

[6 marks]

**Continued...**

(c) A 208-V, 60-Hz, six-pole, Y-connected, 25-hp class B design induction motor is tested in the laboratory, with the following results:

| | |
|---|---|
| No load test: | 208 V, 24 A, 1400 W |
| Locked rotor test: | 24.6 V, 64.5 A, 2200 W |
| DC test: | 13.5 V, 64 A |

[Note: Class B design: $X_1 = 0.4X_{eq}, X_2 = 0.6X_{eq}$]

(i) Determine the equivalent circuit parameters $R_1, R_2, X_1, X_2, R_C$ and $X_m$.
[10 marks]

(ii) For a slip of 0.05, sketch the per phase equivalent circuit of the motor.
[3 marks]

**Continued...**

## Question 4

(a) Figure Q4(a) shows the one-line diagram of an electrical power system. The ratings of the various components in the power system are given as follows:

| | |
|---|---|
| Generator, G1: | 400 MVA, 64 kV, $R = 10$ %, $X = 90$ % |
| Generator, G2: | 600 MVA, 64 kV, $R = 5$ %, $X = 95$ % |
| Transformer, T1: | 180 MVA, 64/350 kV, $R = 2$ %, $X = 15$ % |
| Transformer, T2: | 150 MVA, 580/50 kV, $R = 2$ %, $X = 10$ % |
| Motor, M: | 120 MVA, 32 kV, $R = 12$ %, $X = 85$ % |

The transmission line has an impedance of $(18 + j42)\ \Omega$, and the static load impedance is $(2.75 + j6.3)\ \Omega$. Consider a base apparent power of 400 MVA and a base voltage of 64 kV at the generator side.

(i) Determine the base voltages and impedances in Regions 1, 2 and 3. [5 marks]

(ii) Draw the impedance diagram of this power system, and clearly indicating all the impedances and their values in per-unit (p.u.) quantities. [8 marks]

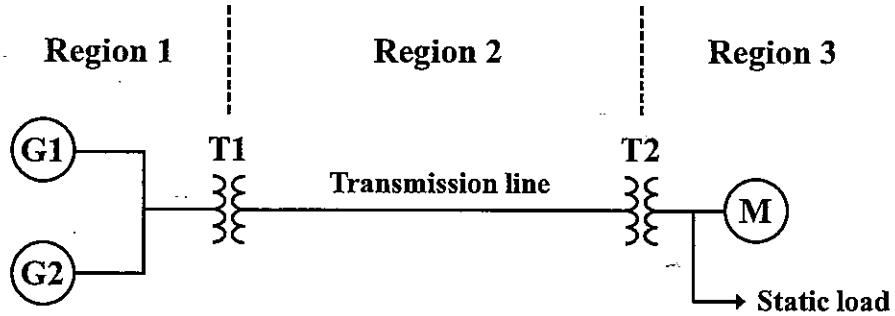



Figure Q4(a)

**Continued...**

(b) For a power distribution system as shown in Figure Q4(b), protective devices (P1, P2, P3, ... P10) are deployed at subfeeders to protect customers (A, B, C, D, E, F) within a community from overload current conditions.

(i) Briefly explain **THREE** basic requirements of protective devices. [3 marks]

(ii) Referring to the fault locations indicated in Figure Q4(b), identify the customer(s) who will be affected by the overcurrent fault. Justify your answer for each case.

- Fault 1
- Fault 2 [4 marks]

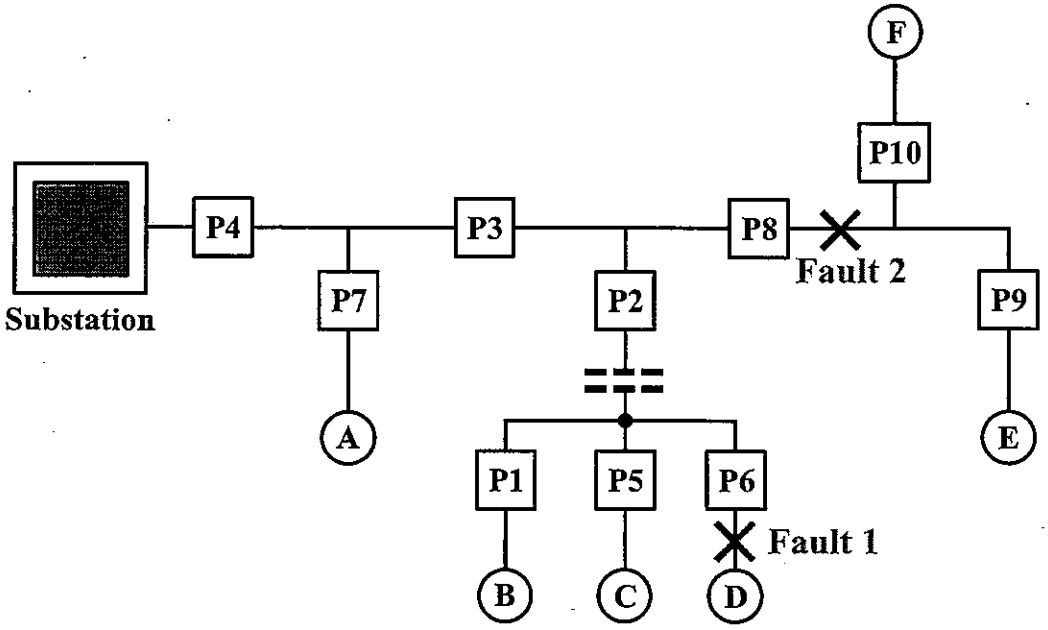



Figure Q4(b)

(c) Figure Q4(c) depicts the time-delay characteristic of a CO-8 Inverse Definite Minimum Time (IDMT) overcurrent relay, which is used to protect a distribution feeder in an electrical power system. The current tap settings of the IDMT relay are available at intervals of 0.5 A. The relay is connected to a 800:5 current transformer and a circuit breaker, and is set to operate when the load current on the feeder exceeds 1040 A.

For a chosen time-dial setting of 4, determine the operating time of the relay for a fault current of 3745 A. [5 marks]

**Continued...**

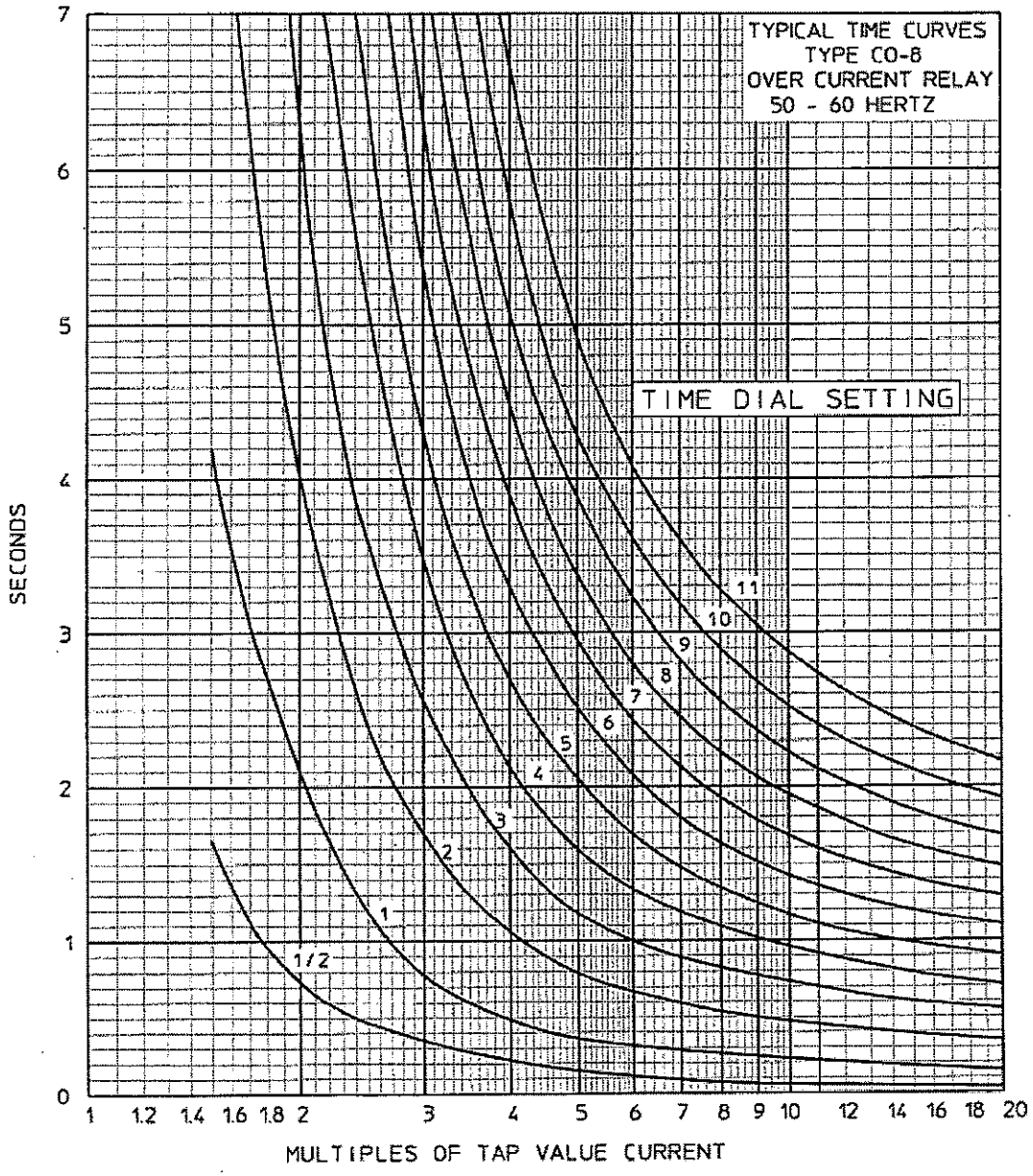



Figure Q4(c)

**End of Questions**

# APPENDIX

## Magnetic Circuits

$$H = \frac{Ni}{l_c}$$

$$B = \mu H = \mu_0 \mu_r H$$

$$\phi = BA$$

$$\Re = \frac{l_c}{\mu A}$$

$$\mathcal{F} = Ni = \phi \Re = H l_c$$

$$\mathcal{F} = ilB \sin\theta$$

$$e_{ind} = vlB \sin\theta_1 \cos\theta_2$$

$$P = \tau\omega$$

## Three-Phase Circuits

Y-Connection: $I_L = I_\phi,\ V_L = \sqrt{3} V_\phi \angle 30°$

Δ-Connection: $V_L = V_\phi,\ I_L = \sqrt{3} I_\phi \angle -30°$

Δ-Y Transformations:

$$R_a = \frac{R_{ac} R_{ab}}{R_{ac} + R_{ab} + R_{bc}}$$

$$R_b = \frac{R_{ab} R_{bc}}{R_{ac} + R_{ab} + R_{bc}}$$

$$R_c = \frac{R_{bc} R_{ac}}{R_{ac} + R_{ab} + R_{bc}}$$

Y-Δ Transformations:

$$R_{ac} = \frac{R_a R_b + R_b R_c + R_c R_a}{R_b}$$

$$R_{ab} = \frac{R_a R_b + R_b R_c + R_c R_a}{R_c}$$

$$R_{bc} = \frac{R_a R_b + R_b R_c + R_c R_a}{R_a}$$

$$P_T = 3|V_\phi||I_\phi| \cos\theta = \sqrt{3}|V_L||I_L| \cos\theta$$

$$Q_T = 3|V_\phi||I_\phi| \sin\theta = \sqrt{3}|V_L||I_L| \sin\theta$$

$$S_T = 3|V_\phi||I_\phi| = \sqrt{3}|V_L||I_L|$$

## Transformers

Turn ratio: $a = \frac{N_P}{N_S} = \frac{V_P}{V_S} = \frac{I_S}{I_P}$

Equivalent circuit (referred to primary):

$$V_s' = aV_S, \quad I_s' = \frac{I_S}{a}$$

$$R_s' = a^2 R_S, \quad X_s' = a^2 X_S, \quad Z_L' = a^2 Z_L$$

$$R_{eqP} = R_P + a^2 R_S, \quad X_{eqP} = X_P + a^2 X_S$$

Equivalent circuit (referred to secondary):

$$V_P' = \frac{V_P}{a}, \quad I_P' = aI_P$$

$$R_P' = \frac{R_P}{a^2}, \quad X_P' = \frac{X_P}{a^2}$$

$$R_{eqS} = R_S + \frac{R_P}{a^2}, \quad X_{eqS} = X_S + \frac{X_P}{a^2}$$

Short-Circuit Test

$$Z_{eq} = \frac{V_{SC}}{I_{SC}}, \quad R_{eq} = \frac{P_{SC}}{{I_{SC}}^2}$$

$$X_{eq} = \sqrt{{Z_{eq}}^2 - {R_{eq}}^2}$$

Open-Circuit Test

$$R_C = \frac{{V_{OC}}^2}{P_{OC}}, \quad S_{OC} = V_{OC} I_{OC}$$

$$Q_m = \sqrt{{S_{OC}}^2 - {P_{OC}}^2}$$

$$X_m = \frac{{V_{OC}}^2}{Q_m}$$

Voltage Regulation

$$VR = \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\%$$

Efficiency $\eta = \frac{P_{out}}{P_{in}} \times 100\%$

**End of Paper**